Intraoperative low-field MR-guided frameless stereotactic biopsy for intracerebral lesions

Burkhardt, J K ; Neidert, M C ; Woernle, C M ; Bozinov, O ; Bernays, R L

Abstract: BACKGROUND: To present our intraoperative low-field magnetic resonance imaging (ioMRI) technique for stereotactic brain biopsy in various intracerebral lesions. METHOD: Seventy-eight consecutive patients underwent stereotactic biopsies with the PoleStar N-20/N-30 ioMRI system and data were evaluated retrospectively. Biopsy technique included ioMRI before surgery, followed by insertion of the biopsy cannula in the lesion, and ioMRI before and after biopsy. Statistical analysis was performed to compare subgroups using Excel and SPSS statistic software. RESULTS: In all patients, stereotactic biopsy was possible, with a mean intraoperative surgery time of 86.2 ± 28.6 min and a mean hospital stay of 11.6 ± 4.6 days. In 97.4 % (n = 76), histology was conclusive, representing 58 brain tumors and 18 other pathologies. Five patients were biopsied previously without conclusive diagnosis, and all biopsies were conclusive this time. Mean cross-sectional lesion size in MRI T1 with contrast (n = 64) was 6.9 ± 5.7 cm(2), and in lesions without T1 contrast enhancement (n = 14), T2 mean cross-sectional lesion size was 5.5 ± 3.9 cm(2). Mean distance from the cortex surface to the lesion was 3.4 ± 1.2 cm. One patient suffered from a postoperative wound dehiscence; neither clinically or radiologically significant hemorrhage after surgery, nor intraoperative complications occurred. CONCLUSIONS: Low-field ioMR-guided frameless stereotactic biopsy accurately diagnosed different intracerebral lesions without major complications for the patients, and within an acceptable surgery time and hospital stay. In repeated non-conclusive biopsies in particular, low-field ioMRI offers a technique for arriving at a diagnosis.

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CLINICAL ARTICLE - NEUROSURGICAL TECHNIQUES

Intraoperative low-field MR-guided frameless stereotactic biopsy for intracerebral lesions

Jan-Karl Burkhardt · Marian C. Neidert · Christoph M. Woernle · Oliver Bozinov · René-Ludwig Bernays

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Conclusions Low-field ioMR-guided frameless stereotactic biopsy accurately diagnosed different intracerebral lesions without major complications for the patients, and within an acceptable surgery time and hospital stay. In repeated non-conclusive biopsies in particular, low-field ioMRI offers a technique for arriving at a diagnosis.

Keywords Intracerebral lesion · Intraoperative magnetic resonance imaging (ioMRI) · Low-field · Stereotactic brain biopsy

J.-K. Burkhardt (✉) · M. C. Neidert · C. M. Woernle · O. Bozinov · R.-L. Bernays
Department of Neurosurgery, University Hospital Zurich, Frauenklinikstr.10,
8091 Zurich, Switzerland
e-mail: Jankarl.burkhardt@gmail.com

R.-L. Bernays
Department of Neurosurgery, Klinik Hirslanden, Witellikerstr. 40,
8032 Zurich, Switzerland

Introduction

Carrying out a biopsy of intracerebral lesions has become a standard procedure in the neurosurgical routine within the last decades [8, 12, 18]. Accompanying major improvements in imaging modalities, surgical biopsy techniques have gradually evolved over time. The first biopsies were performed free-handed based on preoperative computed tomography (CT) scans for planning and navigation [8, 18]. With novel intraoperative imaging modalities such as navigation, ultrasound (ioUS) or magnetic resonance imaging (ioMRI) lesions can be biopsied more precisely with intraoperative control [2, 5, 9, 10, 17]. Since stereotactic navigated biopsies do not need additional intraoperative images, the technique is simple and fast. However, precision might be limited due to intraoperative brainshift. Intraoperative imaging techniques such as ioUS or ioMRI are able to overcome this limitation. Nevertheless, ioUS needs a larger approach (craniotomy) for adequate use of the probe, and its scan coverage in deep lesions is limited. The ioMRI technique has an advantage because lesion location (deep or superficial) does not limit imaging quality. IoMRI is also not dependent on a certain surgical approach for the imaging procedure, while ioUS is [9]. Low-field ioMRI, such as PoleStar (0.15 T), was

introduced into clinical practice within the last decade and simplified the first open MRI techniques [2, 4, 10–13]. In this study, we report our stereotactic brain biopsy results using the PoleStar N-20 and N-30 to assess the benefit of low-field ioMRI in stereotactic brain biopsies.

Materials and methods

Patient data

IoMRI (PoleStar N-20 or N-30) guided stereotactic biopsy of different intracerebral lesions was performed in 78 patients at our department between 2006 and 2011. Mean age of the patients was 57.5 ±18.8 years (range of 2–87y), including 46 male (59 %) and 32 female (41 %) patients. Patients were either positioned in supine or prone position and all intracranial lesions were located supratentorially, including 37 (47.4 %) in the right and 35 (44.9 %) in the left hemisphere. Six lesions (7.7 %) were located in the midline.

Intraoperative MRI (ioMRI) system

PoleStar N-20 (01/2006-08/2010) or N-30 (09/2010-12/2011) (both Medtronic, Louisville, USA) were used as the ioMRI system according to the manufacturer's protocol. A detailed description of the system has already been published [12]. Briefly, the system is designed to be located under the operating table and can be raised into imaging position as needed during surgery. The system operates with two vertically oriented magnetic poles (27 cm gap), with the transmitting coils, each with a magnet field strength of 0.15 T situated on the outside of each pole.

Operative technique and trajectory guide

Under general anesthesia, the patient was positioned in an MRI-compatible head fixation frame to allow imaging of the biopsy needle during surgery. After placement of a MRI receiving coil on the patient head, a passive infrared reference frame was secured to the head fixation.

Before surgery, the magnet under the operating table was raised into imaging position to acquire preoperative images. A 1–7 minT1 weighted sequence (T1) with contrast (gadolinium) and/or a T2 weighted sequence (T2) were performed in all patients to localize the intracerebral lesion. Based on the navigation system (Medtronic), the trajectory for the biopsy was determined. After skin incision, a standard burr hole was made and dura/pia were incised. The base of the trajectory guide was then secured or "snapped" in the burr hole, followed by confirmation of trajectory using the navigation stick. The software allowed now the calculation of the distance to the lesion. The biopsy cannula was then placed through the trajectory guide and inserted to the calculated depth. Successful targeting was confirmed by a second scan. Samples were then taken from all directions of the lesion and sent for neuropathological examination. Before stepwise closure, another scan was performed to rule out intraoperative complications, such as intracerebral bleeding.

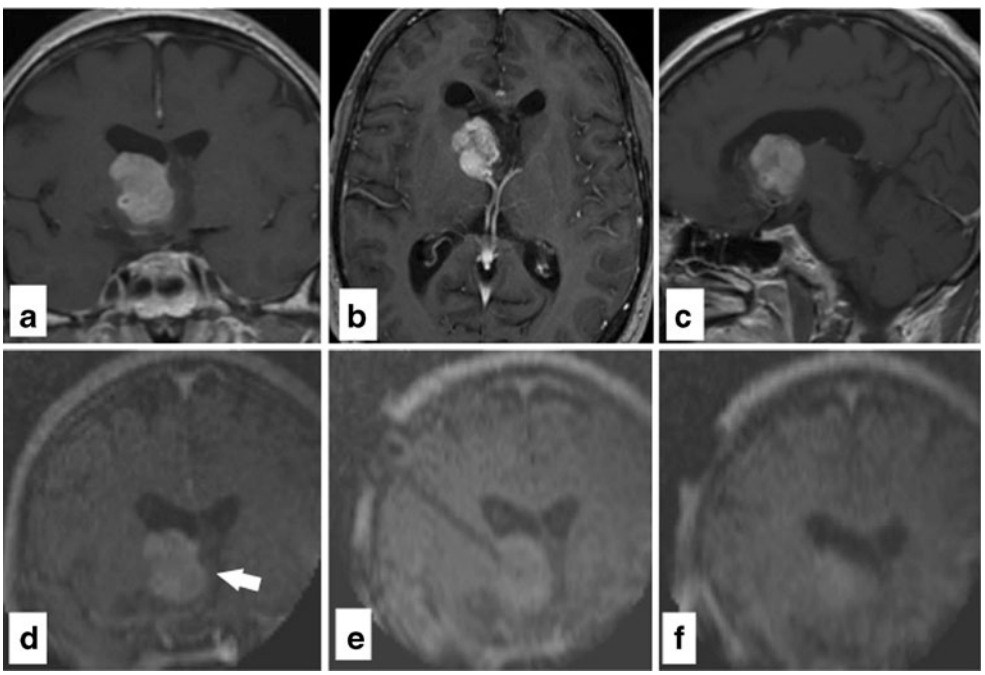

Fig. 1 A 50-year-old male patient showed a right-sided thalamic lesion in the preoperative 1.5 T MRI (**a** coronal, **b** axial and **c** sagittal plane in T1 with contrast) and the low-field 0.15 ioMRI before biopsy (**d** coronal plane in T1 with contrast). IoMRI confirmed correct location of the cannula during biopsy (**e**) and excluded intraoperative complications after biopsy (**f**). Glioblastoma was diagnosed after pathological examination

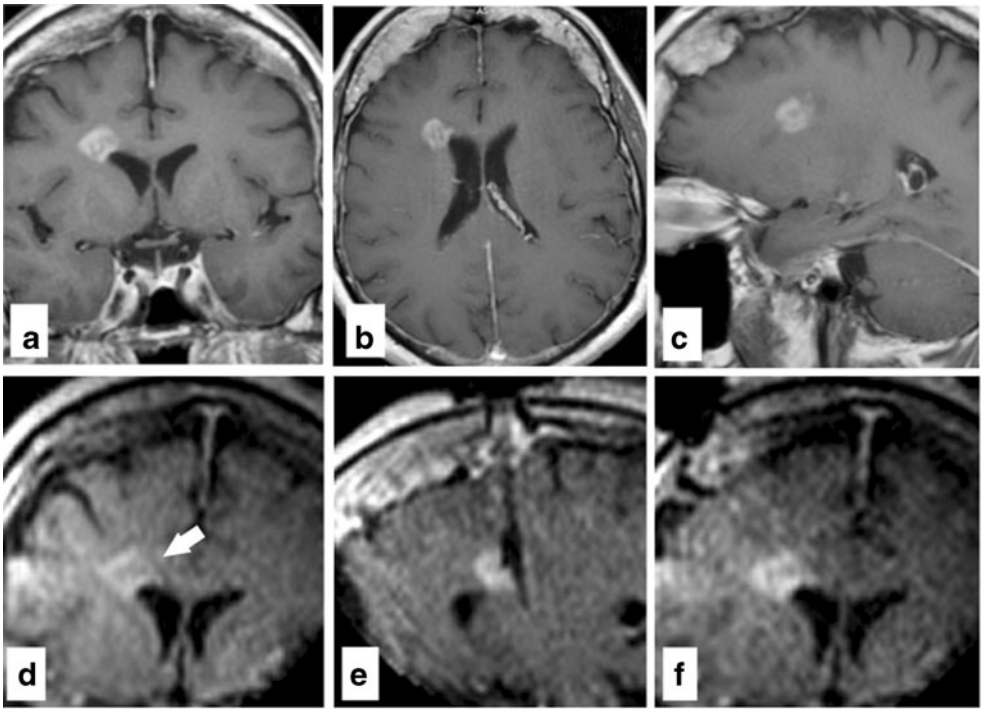

Fig. 2 a 54-year-old female patient showed a right-sided periventricular lesion in the preoperative 1.5 T MRI (**a** coronal, **b** axial and **c** sagittal plane in T1 with contrast) and the low-field 0.15 ioMRI before biopsy (**d** coronal plane in T1 with contrast). IoMRI confirmed correct location of the cannula during biopsy (**e**) and excluded intraoperative complications after biopsy (**f**). B-cell lymphoma was diagnosed after pathological examination

Statistical analysis

Descriptive statistics and non-parametric tests were used to determine statistical significance, as appropriate. All p values are two-sided and statistical significance was evaluated at the 0.05 alpha level. All statistical analyses were performed in SPSS (PASW) Version 20.0 (SPSS Inc., Chicago, IL) and Microsoft Excel Version 14.2. Tumor lesion size was assigned by a senior board-certified neuroradiologist and the slices of greatest cross-sectional area of the enhanced tumor (MRI T1 sequence with contrast) or non-enhanced tumor (MRI T2 sequence) were chosen for size analysis.

Results

In all 78 patients, ioMRI confirmed the correct placement of the biopsy cannula inside the intracerebral lesion before biopsy. In two cases, however, neuropathological examination was not conclusive, showing a non-specific brain tissue inflammation.

The conclusive 76 biopsies mostly represented brain tumors (n=58, 74.4 %); in more detail, 34 glioblastoma multiforme (Fig. 1), one gliosarcoma, six anaplastic astrocytomas (WHO Grad III), three low grade astrocytomas (WHO Grade II), nine B-cell lymphomas (Fig. 2), three metastases, one meningioma (WHO Grade I) and one germinoma. Histopathological examination of the remaining 18 lesions showed a brain abscess in eight cases, two cases of HIV-associated toxoplasmosis, three chronic demyelinating diseases, one acute demyelinating disease, two amyloidangiopathy-associated hematomas, one progressive multifocal leukoencephalopathy and one radiation necrosis (Table 1).

All intracerebral lesions were located supratentorially in the frontal (n=20), temporal (n=10), parietal (n=8) and occipital (n=2) lobe, as well as in the corpus callosum (n=15), nucleus

Table 1 Overview of diagnosis

Diagnosis	Patients (n)	Percentage (%)
Brain Tumors	58	74.4
Glioblastoma Multiforme	34/58	58.6
B-Cell Lymphoma	9/58	15.6
Anaplastic Astrocytoma	6/58	10.3
Low Grad Astrocytoma	3/58	5.2
Metastasis	3/58	5.2
Gliosarkoma	1/58	1.7
Meningioma (WHO Grade I)	1/58	1.7
Germinoma	1/58	1.7
Brain Abscess	8	10.2
Chronic Demyelinating Disease	3	3.7
Toxoplasmosis	2	2.6
Amyloid Angiopathy	2	2.6
Acute Demyelinating Disease	1	1.3
Progressive Multifocal Leukoencephalopathy	1	1.3
Radiation Necrosis	1	1.3
Non-specific Brain Tissue Inflammation	2	2.6
Total	78	100

Table 2 Localization of lesions

Localization	Patients (n)	Percentage (%)
Right Hemisphere	37	47.4
Left Hemisphere	35	44.9
Midline	6	7.7
Frontal	20	25.6
Temporal	10	12.8
Parietal	8	10.3
Occipital	2	2.6
Corpus Callosum	15	19.2
Thalamus	13	16.7
Putamen	5	6.4
Nucleus Caudatus	4	5.1
Clivus	1	1.3
Total	78	100

caudatus (n=4), putamen (n=5), thalamus (n=13) and clivus (n=1) (Table 2). The mean cross-sectional lesion size of the intracerebral lesions with contrast enhancement in T1 (n=64) was 6.9±5.7 cm^2 (range 0.6–27.2 cm^2). The mean cross-sectional lesion size in lesions without contrast enhancement (n=14) was 5.5±3.9 cm^2 (range 1.5–14.8 cm^2) in the T2 sequence. Mean distance of the cortex surface to the intracerebral lesion was 3.4±1.2 cm (range 1.1 – 6.2 cm) (Table 3).

For 73 patients (93.5 %), the stereotactic biopsy was the first time of biopsy. In five cases (6.5 %), a biopsy had previously been performed. One patient received stereotactic biopsy with ioMRI for a different lesion, four patients received open biopsy without ioMRI for the same lesion, without a conclusive result in three cases. In all of these five patients, neurohistopathological diagnosis after ioMRI-guided biopsy was conclusive, this time including two low grade astrocytoma (WHO Grade II), one B-cell lymphoma, one abscess and one chronic demyelinating disease (Table 4).

Mean intraoperative surgery time was 86.2±28.6 min (range 35–180 min) and intracerebral lesions could be detected with contrast T1 ioMRI in 64 cases—additional T2 sequences were useful in 14 cases. In 59 cases, the surgeon was a board-certified neurosurgeon (attending), and in 19 cases surgery was performed by a resident with the supervision of an attending. Mean surgery time for the procedures performed by the attending alone was 83.8±28.8 min compared to 93.4±29.1 min performed by a resident with the supervision of an attending (p=0.06). Comparing stereotactic procedures performed with the two ioMRI systems N-20 (n=54) and N-30 (n=24), mean surgery time was comparable with 90.1±29.2 min versus 81±27.1 min (p=0.126). Both non-conclusive biopsies were performed with the N-20, and one patient who suffered from impaired wound healing after biopsy was operated with the N-30 (Table 5).

Mean duration of hospital stay was 11.6±4.6 days (range 4–21 da,ys) and immediate postoperative course was uneventful in 77 patients. One patient, however, suffered from impaired wound healing in the absence of infection at postoperative day 6, requiring surgical revision. In eight patients, the immediate postoperative CT scan showed minor, non-space occupying hemorrhage in the area of the biopsy. None of these patients were symptomatic and needed second surgery.

Discussion

In this study, we present the largest study in the literature of intraoperative low-field MR-guided frameless stereotactic biopsy for intracerebral lesions. Our technique was safe in all 78 cases, with neither intraoperative nor symptomatic postoperative complications except one patient suffered from a postoperative wound dehiscence. Biopsy led to a diagnosis in 97.4 % (76/78) of the cases.

In general, imaging-guided techniques, and especially the low-field MR-guided frameless stereotactic biopsy technique, has the advantage of taking brainshift into account, ensuring that the biopsy is taken in the area of interest and ruling out complications such as hemorrhages at the end of the procedure [2, 14]. Although purchase and maintenance costs are much higher than in comparative biopsy techniques, running imaging cost can be saved once the low-field MRI technique is installed. Preoperative MR navigation sequences or postoperative scans to rule out complications are not necessary, since biopsy can be planed and navigated based on an intraoperative low-field MR scan before surgery, and complications such as hemorrhage can be ruled out by obtaining an intraoperative scan after completion of the procedure. Especially in small intracerebral lesions located in deep brain areas far away from the brain surface, an intraoperative imaging-guided biopsy

Table 3 Magnetic resonance imaging (MRI) features

Lesion Characteristics	Number (n)	Percentage (%)	Mean Lesion Size (cm^2)	SD	Range
T1 with contrast enhancement	64	82.1	6.9	5.7	0.6–27.2
T2 without T1 contrast enhancement	14	17.9	5.5	3.9	1.5–14.8
	Number (n)		Mean Distance (cm)	SD	Range
Cortex Surface to Lesion	78	100	3.4	1.2	1.1–6.2

Table 4 Patient and surgery characteristics

Patient Characteristics	Number (n)	Percentage (%)	Age (years)	SD	Range
Overall	78	100	57.5	18.8	2.0–87.0
Female	32	41	53.8	19.8	2.0–87.0
Male	46	59	60.1	17.8	13.0–86.0
Biopsy Type	Number (n)	Percentage (%)			
Primary Biopsy	73	93.5			
Biopsy performed before	5	6.5			
non conclusive before	3	60			
conclusive diagnosis this time	5	100			
Surgery features		Patients (n)	Percentage (%)		
Hospital Stay in days (SD)	11.6 (4.6)	78	100		
Surgery time in minutes (SD)	86.2 (28.6)	78	100		
Intraoperative complications		0	0		
Postoperative asymptomatic hemorrhage CT scan		8	10.3		
Wound Healing Complication		1	1.3		

technique is superior to other techniques [2]. In our study, most of the lesions were located at a large distance from the brain surface with a mean distance from the cortex surface to the intracerebral lesion of 3.4 cm with an upper range of up to 6.2 cm. For these deep-located lesions, our low-field MRI biopsy technique was able to reach the lesion using imaging guidance.

Previously published studies using low-field MR-guided frameless stereotactic biopsy techniques showed similar results with regards to our study. Pilot studies using intraoperative MR-guided techniques with a range of 0.12 to 0.2 Tesla reported on biopsy diagnosis rates between 90 and 100 % [3, 6, 10, 15]. A larger study by Schulder and Spiro using the PoleStar N-20 0.15 T system on 39 patients showed the same diagnosis rate of 97.4 % (38/39) compared to our study, with any intraoperative/postoperative biopsy related mortality and morbidity [14]. Similarly to our two cases without accurate diagnosis, the biopsy cannula in one case in Schulder and Spiro study was confirmed to be in the area of interest during biopsy [14]. Although not provable, the correct location of the cannula during surgery and an unspecific histopathological finding suggests that these lesions were more likely really to be unspecific inflammations and not indicative of an inability to diagnose these lesions using this technique.

Our histology results after biopsy were comparable to previously published studies including mostly higher-grade primary brain tumors and rarely chronic demyelinating diseases or infections [12]. However, with regard to the location, nearly half of our treated patients had a lesion in the corpus callosum, thalamus or basal ganglia (Table 2). In previously published studies lesions were more likely to be biopsied in the frontal, temporal, parietal or occipital lobes [12, 14]. Our mean surgery time of 1.4 h was within the range of previously published studies. For instance, our previously published study on biopsies using an open 0.5 T MRI was 1.2 h, and Quinn et al. presented a mean surgery time of 1.7 h using the Polestar N-20 MRI [2, 12]. There was also no significant difference in surgery time between residents and attendings as the performing surgeon in this study.

Compared to other biopsy techniques, we were able to achieve a high histopathological diagnosis yield of 97.4 % with our method. Tsermoulas et al. showed in a series of 124 consecutive patients with different biopsy methods such as freehand, ultrasound guided, frameless and frame-based stereotactic methods that no significant differences between the

Table 5 Surgeons' education level and ioMRI systems

	Patients (n)	Percentage (%)	Surgery time (minutes)	SD	
Overall	78	100	86.2	28.6	
Surgeons' education level					
Attending	59	75.6	83.8	28.8	$p=0.06$
Resident	19	24.4	93.4	29.1	
ioMRI system					
N-20	54	69.2	90.1	29.2	$p=0.126$
N-30	24	30.8	81	27.1	

methods could be detected - the total histopathological diagnosis rate was 93.5 % [16]. Also, other groups such as Air et al. or Gempt et al. reported in 284 and 91 patients using frameless stereotactic needle biopsies a diagnostic yield of 89.8 % and 93.8 %, respectively [1, 7]. Although many different biopsy methods describe a high diagnosis rate, we suppose that with an intraoperative imaging-based method such as low-field MRI, the yield might be even higher, as seen in our study. Also, with regards to repeated biopsies, we could show that intraoperative low-field MR-guided frameless stereotactic biopsy had excellent results in cases that had been biopsied before. In our study, five patients (6.5 %) had already been biopsied. One patient received stereotactic biopsy with ioMRI for a different lesion, and four patients received open biopsy without ioMRI for the same lesion without a conclusive result in three cases. In all of these five patients, pathological examination after ioMRI-guided biopsy was conclusive this time. Especially in the three cases that had not been conclusive using a different biopsy technique, this technique was useful in arriving at a diagnosis. Therefore, in a situation of non-conclusive biopsy, a patient might benefit from a second biopsy using intraoperative low-field MR-guided frameless stereotactic technique to obtain a diagnosis.

Conclusion

In this study, frameless stereotactic biopsy with a low-field ioMRI accurately diagnosed different intracerebral lesions with neither intraoperative nor symptomatic postoperative complications for the patients within an acceptable surgery time and hospital stay. In repeated non-conclusive biopsies in particular, low-field ioMRI offers a technique for arriving at a diagnosis.

Conflict of interest None.

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